DYNAMICALLY TUNED HIGH-Q AC-DIPOLE IMPLEMENTATION[*]

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Abstract

AC-dipole magnets are typically implemented as a parallel LC resonant circuit. To maximize efficiency, it's beneficial to operate at a high Q. This, however, limits the magnet to a narrow frequency range. Current designs therefore operate at a low Q to provide a wider bandwidth at the cost of efficiency. Dynamically tuning a high Q resonant circuit tries to maintain a high efficiency while providing a wide frequency range. The results of ongoing efforts at BNL to implement dynamically tuned high-Q AC dipoles will be presented.

INTRODUCTION

Work on a new spin flipper for RHIC (Relativistic Heavy Ion Collider) incorporating multiple dynamically tuned high-Q AC-dipoles has been developed for RHIC spin-physics experiments. A spin flipper is needed to cancel systematic errors by reversing the spin direction of the two colliding beams multiple times during a store [1]. The spin flipper system currently consists of four DC magnets and three AC-dipoles and will go to five AC-dipoles. Multiple AC-dipoles are needed to localize the driven coherent betatron oscillation inside the spin flipper. Having multiple AC-dipoles that require precise control over amplitude and phase makes it necessary to implement them as dynamically tuned high-Q resonant circuits. One of the major challenges was to design of a new magnet and the proper topology to drive it. The topology is required to be both efficient and serviceable.
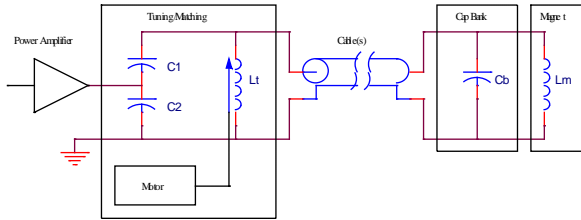

Figure 1: RHIC High-Q AC-dipole simplified schematic.

HIGH-Q AC-DIPOLE SYSTEM

Figure 1 is a simplified schematic of the present implementation. This topology places the bulk of the capacitance at the magnet. A pair of heliax coaxial cables connects the capacitor bank to the tuning chassis in the service building. Tuning is accomplished via a motor driven variable air-gap inductor. A servo loop adjusts the air gap to maintain the system at resonance.

This topology was initially chosen to support solid state (switched capacitor) tuning which required the tuning to be done outside of the ring in order to protect the

semiconductor (MOSFET) switches from radiation damage. However, due to scheduling and concerns over switching distortion, solid state tuning was not implemented.

Existing AC-dipole systems

For comparison, figure 2 is a simplified schematic of the existing RHIC AC-dipoles [2] and figure 3 of the CERN LHC [3] and the FNAL Tevatron [4] AC-dipoles. For clarity, these schematics only illustrate the location of major components. In all cases the transmission line is the dividing line between the components in the service building and in the ring. The placement and use of the transmission line is a key difference between approaches.
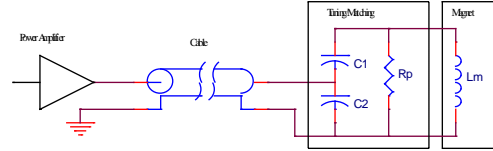

Figure 2: RHIC AC-dipole simplified schematic.

RHIC AC-dipoles

The RHIC AC-dipoles matches and tunes the AC-dipoles at the magnet. This approach tries to terminate the transmission line with its characteristic impedance. Although the magnet was designed as a high-Q air-core, the Q is deliberately spoiled (Rp). Since the resonant impedance is greater than amplifier/transmission line impedance, a capacitive step-up matching network was used (C1, C2).
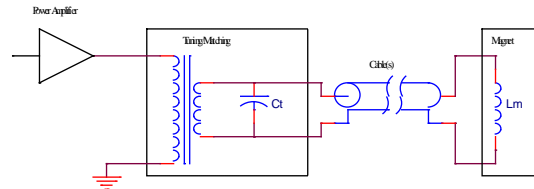

Figure 3: LHC/Tevatron AC-dipole simplified schematic

LHC and Tevatron AC-dipoles

The LHC/Tevatron approach does the tuning and matching at the service building. For this approach the transmission line current is the magnet current. Furthermore, since low impedance kicker magnets are used, the transmission line is terminated with an impedance that's much lower than its characteristic impedance; the transmission line therefore forms a parasitic series inductance. This inductance increases the peak energy stored.

Key difference

The RHIC High-Q AC-dipoles also do not terminate the transmission line with its characteristic impedance. However, since the capacitor-bank and magnet parallel impedance is a lot greater than the transmission line's characteristic impedance, the transmission line looks capacitive. This capacitance is not harmful and actually reduces the amount of capacitance that has to be added to from the resonant circuit. It's this difference that allows the tuning chassis to be separated from the magnet by long (400ft or 122m long) cables and have a minimal effect on efficiency. The cable capacitance makes up about 10% of the total system capacitance and can be viewed as a stretched out capacitor bank. The cable current is not uniform and the peak is at different locations based on frequency.
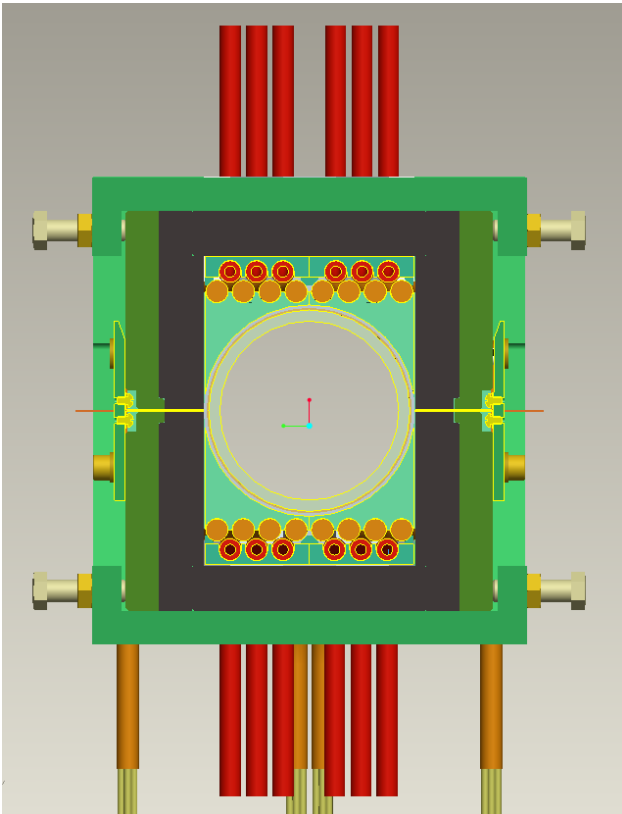

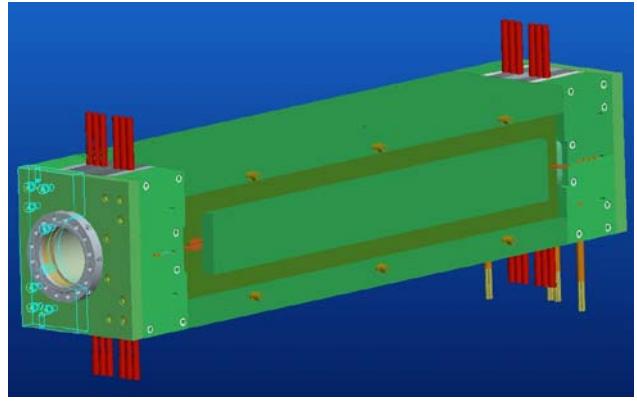Figure 4: RHIC Spin Flipper high-Q AC-dipole magnet cross sectional view

Figure 5: RHIC Spin Flipper high-Q AC-dipole 3D view

MAGNET DESIGN

Referring to figures 4 and 5, the magnet is an eight-turn litz-wire wound ferrite core window frame magnet build around a ceramic beam pipe. This geometry was chosen over the air-core geometry used for the existing RHIC AC-dipoles because it can accommodate a larger aperture with a shorter effective path length (l_e). This shorter path length translates into less stored energy, less reactive power and therefore less power loss. This geometry also more easily satisfies the field-fidelity requirements.

TUNING CHASSIS

The tuning chassis houses the tuning coil and capacitive matching network (C1 and C2 in figure 1) that form a parallel LC circuit. When the tuning coil gap is set to minimum (maximum inductance) this LC circuit looks capacitive and pulls the frequency lower. As the gap increases the circuit becomes inductive and starts pulling the frequency higher.
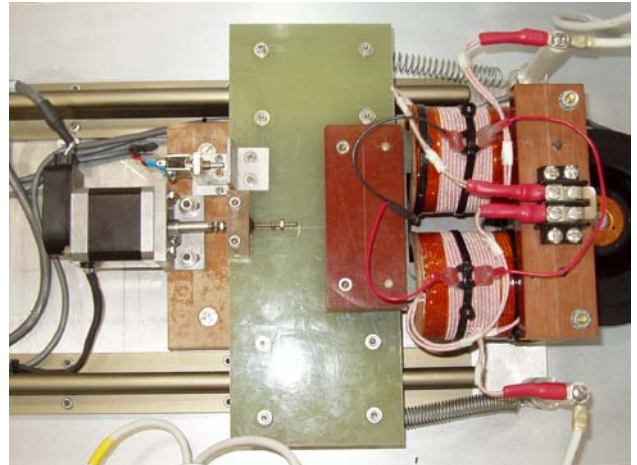

Figure 6: Tuning coil assembly

TUNING COIL

The tuning coil is composed of two litz-wire wound coils mounted on the legs of two U-shaped cores. One core is fixed (right side of figure 6) and the other movable by the stepper motor (left side of figure 6) and thus

produces a variable air gap. As implemented, the relationship between the air gap size and center frequency is nearly linear.

CONTROLS

The prototype control system was based on commercial Xilinx development boards. This initial version runs two servo loops per magnet. The first loop keeps the magnet at the resonant frequency by comparing the magnet current to amplifier drive current phase and adjusting the tuning coil air-gap to keep these in quadrature. The second loop operates as an automatic gain control (AGC) and adjusts the amplifier drive to maintain the magnet current amplitude. The control system is being overhauled to become more capable and scalable. One planed change is to replace the relatively slow AGC with a fast feedback that tries to match the magnet current to a reference waveform. This change will allow much tighter control over phase and will use the amplifier's headroom to fine-tune the magnet frequency until the slower frequency loop settles.

CONCLUSION

Testing has validated this dynamically tuned high-Q AC-dipole design. The basic requirements of tuning range and magnet current were easily met. Beam based measurements showed the AC-dipoles to be well matched. However, continuing development is ongoing.

REFERENCES

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